

# QSO Absorption Lines: The UV Rest–Frame from $0 < z < 4$

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**Abstract.** By charting the kinematic, chemical, and ionization conditions of galactic and intergalactic gas over the redshift range  $0 - 4$  with QSO absorption lines, the evolution of chemical abundances, the UV meta–galactic background, and the clustering dynamics of galactic gas can be studied. HIRES/Keck Mg II  $\lambda 2796$  profiles arising in  $z \sim 1$  galaxies are presented and the Mg II kinematic clustering function is given. The intriguing  $z = 0.93$  systems toward Q1206+459 are shown and compared to  $z \sim 2$  HIRES/Keck C IV profiles to illustrate how STIS/HST can be exploited for studies of the high ionization conditions in  $z \leq 1$  Mg II selected systems. The scientific motives and plans for a large IR  $2 \leq z \leq 4$  Mg II survey with the Hobby–Eberly Telescope are presented.

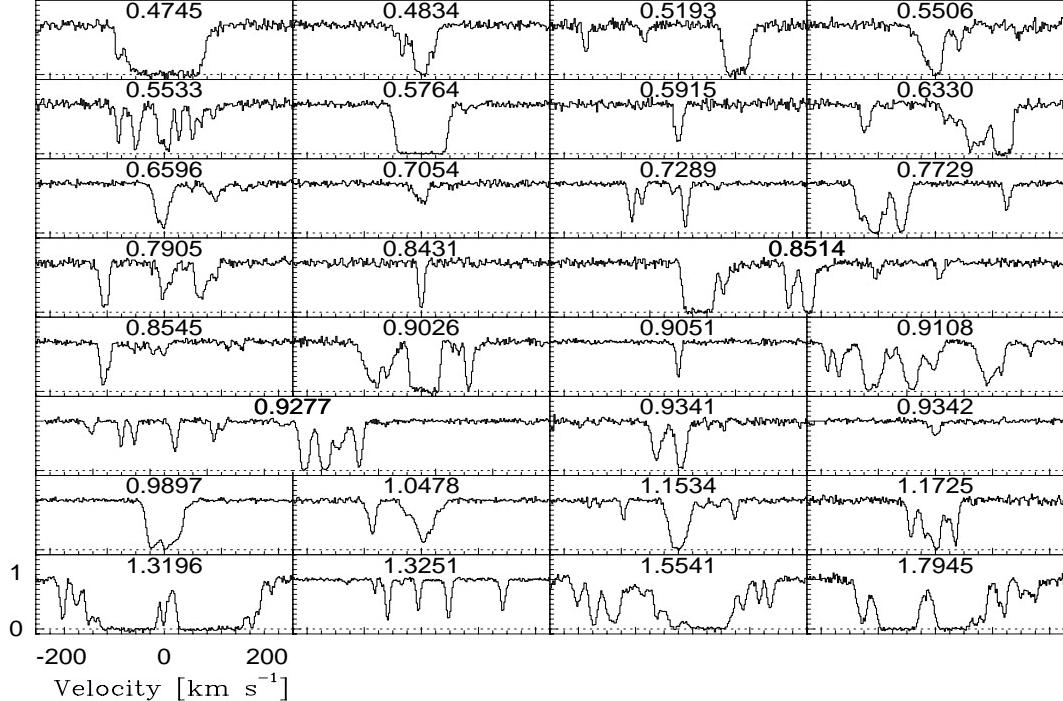
## INTRODUCTION

Though QSO absorption lines have contributed many impressive strides in our understanding of the UV universe (Charlton, this volume), *terra–incognita* remains to be explored and scientifically exploited. A few of the ultimate aims of QSO absorption line studies are to establish the history of cosmic chemical evolution, the shape and intensity of the UV background, the evolving rate of galactic accretion events and star bursting outflows, and the reciprocative roles these play in galactic formation and evolution over  $\sim 95\%$  of the age of the universe. The UV rest–frame gaseous conditions seen in absorption at high redshift do *not* suffer cosmologically induced effects that might otherwise be mistaken as evolutionary processes (i.e. k–corrections). Thus, from  $z \sim 4$  to  $z = 0$ , statistical changes in absorbing conditions, such as profile velocity spreads, numbers of subcomponents, and ionization levels, can be unambiguously attributed to evolution in either the structures, dynamics, numbers, and/or ionization and chemical conditions of UV flux sensitive gas–phase baryons. In this contribution, the unknown “absorbing” UV universe is discussed and scientific motives for its exploration are given.

Neutral gas is easily traced using the Ly $\alpha$   $\lambda 1216$  transition. Traditionally, the Mg II  $\lambda\lambda 2796, 2803$  and the C IV  $\lambda\lambda 1548, 1550$  resonant doublets have been used

as tracers of the low and high ionization gas, respectively, because they are very strong in absorption and have easily identified doublet patterns.

Presented in Figure 1 are the MgII  $\lambda 2796$  profiles from a HIRES/Keck survey [1]. For 15 of these systems, Churchill et. al [2] compared the absorption and luminous properties of the galaxies. They concluded that MgII absorbing gas exhibits no clear spatial distribution or systematic kinematics and suggested the gas results from episodic galactic processes. The implications for galaxy evolution are not entirely clear. The unexplored kinematics of the high ionization gas (i.e. CIV) in these systems will be key for further interpretation.

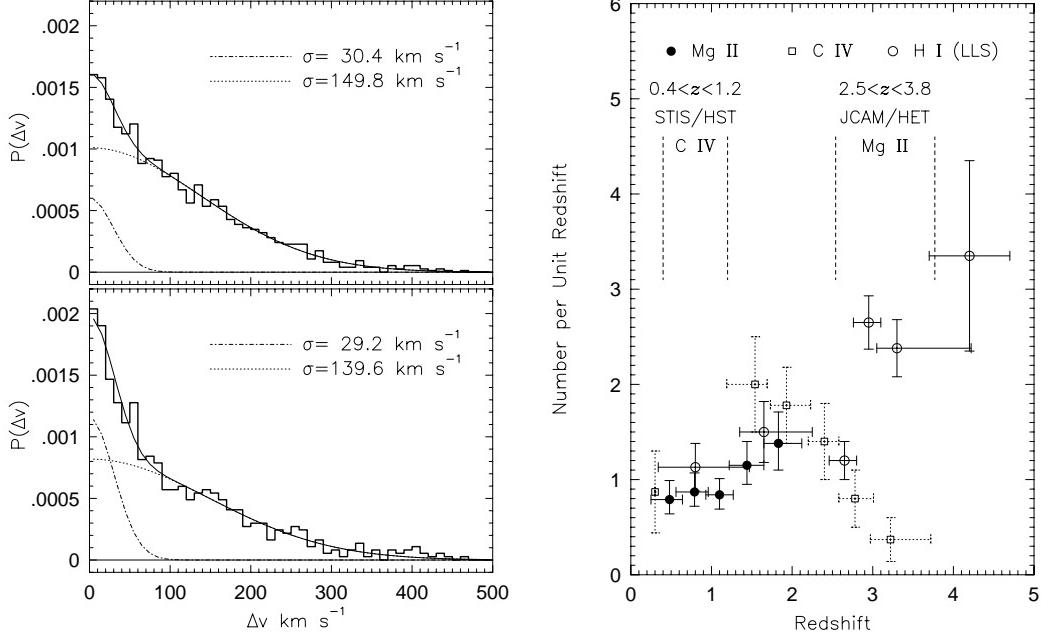


**FIGURE 1.** The  $z < 2$  HIRES/Keck MgII  $\lambda 2796$  transition in absorption presented in line of sight velocity of the rest frame and in order of increasing redshift (marked above the continuum). The absorption arises in the extended low ionization gas surrounding galaxies. For each galaxy, the  $\lambda 2803$  transition and several FeII transitions have also been observed.

Shown in the left panels of Figure 2 are the MgII Two–Point Clustering Functions (TPCFs) of subcomponents (blended “clouds” decomposed with Voigt Profiles). The TPCF gives the probability of finding two clouds separated by  $\Delta v$  in an absorbing system [3]. In principle, parameterizing the TPCF by multi–component Gaussians provides a means for statistically quantifying kinematic evolution by comparing different redshift regimes. Additionally, the TPCFs of low and high ionization gas can be compared at similar epochs for quantifying the both relative ionization and kinematic conditions.

The high resolution spectra required to study either MgII or CIV kinematic evolution from  $0 \leq z \leq 4$  do not exist—nor do the spectra to study their relative

kinematics at  $z \leq 1.2$  and  $z \geq 2.2$ . The former represents 50–70% of the age of the universe and the latter covers the epoch when galaxy evolution is believed to be very active. What data exist, and what remains unknown?

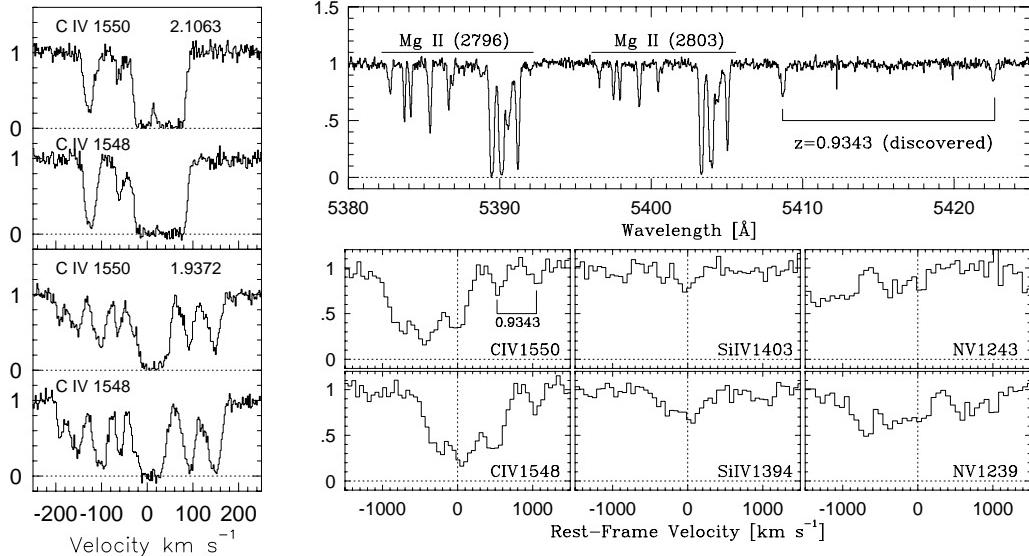


**FIGURE 2.** (left panels) The Two Point Clustering Function of MgII clouds in galactic halos. The upper panel is for  $0.4 \leq z \leq 1.7$ , and the lower panel is for  $0.4 \leq z \leq 1.0$ , the latter presented because the higher redshift subsample is biased toward the strongest absorption strengths. — (right panel) The number per unit redshift for tracers of neutral (H I), low (Mg II), and high (C IV) ionization gas (adapted from Steidel 1993 [7]). The unexplored UV absorbing universe and the required technology are shown.

The numbers of neutral, low, and high ionization systems are shown in the right panel of Figure 2. These numbers are the product of system number density and gas cross section (ionization and metallicity dependent). MgII has been surveyed from  $0.3 < z < 2.2$  and traces the number of Lyman limit systems (LLS). CIV has been surveyed from  $1.2 < z < 3.7$  and shows a dramatic increase in the number of strong systems. The HST Key Project will soon provide overlap between CIV and MgII for  $z \leq 1.2$  (low resolution only). The  $z \leq 1.2$  CIV kinematics are unknown, and MgII is unexplored for  $z \geq 2.2$ . High resolution spaced-based (UV) spectra are needed to extend CIV kinematic studies to  $z \leq 1.2$ . Near Infrared (IR) spectra are needed for a *complete and uniform* survey of MgII to  $z \geq 2.2$ , followed by a higher resolution study of the gas kinematics. These data are necessary if we are to establish a complete picture of absorbing gas to  $z = 4$  for tracking the UV background, chemical evolution, and inferring their roles in galactic evolution.

## DETAILED HIGH IONIZATION AT $Z \leq 1.2$

Consider the  $z = 0.927$  systems shown in the upper right panel of Figure 3. The complex Mg II doublets have a velocity spread of  $500 \text{ km s}^{-1}$ . An additional system is present  $1100 \text{ km s}^{-1}$  to the red, at  $z = 0.934$ . The lower right panels show the CIV, SiIV  $\lambda\lambda 1393, 1402$  and Nv  $\lambda\lambda 1238, 1242$  doublets aligned by their zero point velocities. The CIV doublet has not been resolved, but the profile suggests complex kinematics. In the “CIV1550” panel, note the previously unreported CIV doublet from the  $z = 0.934$  system.



**FIGURE 3.** (right panels) The  $z \sim 0.93$  cluster of systems toward QSO 1206+459 (FOS/HST data courtesy D. Schneider). — (left panel) An example of resolved CIV profiles. These HIRES/Keck CIV profiles show each transition of the doublet highly resolved into multiple subcomponents (upper panels:  $z = 2.106$ ; lower panels:  $z = 1.937$ ).

Photoionization modeling (CLOUDY) of the MgII profiles, Ly $\alpha$  (not shown), CIV, SiIV, and Nv equivalent widths, was unsuccessful at matching the data (the ionization parameter and H $I$  column densities were varied for each subcomponent). Apparently, the systems are not multiple single-phase photoionized “clouds” (cf. [4]). The gas could be shock heated (starburst), or the high ionization gas could be intercluster material not spatially distributed with the low ionization gas. An example of how the FOS/HST CIV profiles may appear when resolved is shown in the left panels of Figure 3. Three galaxy candidates, one with a confirmed redshift, have been identified within  $10''$  of the QSO. High resolution STIS/HST spectra are required if we are to gain an appreciation of gas associated with galaxies and their environments.

A sample of 15 systems have been selected by their HIRES/Keck MgII absorption properties for a STIS/HST study to obtain the first view of the velocity spreads and cloud–cloud clustering of CIV in  $z \sim 1$  galactic halos. This program allows the

first direct comparison of MgII and CIV kinematics in  $z \sim 1$  galaxies. Additionally, the  $z \leq 1$  CIV TPCF from STIS can be compared to that measured at  $z \sim 3.0$  [6], allowing a direct quantification of the kinematic evolution of high ionization gas.

## THE $2.2 \leq Z \leq 3.8$ UV UNIVERSE

As seen in the right panel of Figure 2, the strong CIV systems increase in number from  $z = 4$  to  $z = 1.2$ . It has been suggested (see [5]) that this rapid evolution is due to an epoch of increased metallicity, and is likely not due to an evolving UV background flux. However, the metallicity enrichment scenario is corroborated only by a few, small, non-uniform data sets of singlet low ionization transitions, and, as such, is plagued by several uncertainties.

A uniform sample of MgII doublets would yield an unambiguous look at how the low ionization gas evolves out to  $z = 4$ , providing the leverage needed to settle the “chemical enrichment – UV flux evolution” debate. With an IR spectrograph attached, the Hobby–Eberly Telescope (HET) is ideally suited for a large MgII survey. At Penn State, we (including Beatty, Charlton, Ramsey, & Schneider) are building JCAM, an  $R = 10,000 - 20,000$  IR spectrograph, for the HET. With JCAM/HET, we can obtain a  $0.15 \text{ \AA}$   $3\sigma$  rest-frame equivalent width limit for  $2.2 \leq z \leq 3.8$  in  $\sim 1$  hr for a  $V = 19$  QSO.

With the  $R = 10,000$  survey, we will obtain the first uniform and complete sample of low ionization gas to  $z = 4$ . Our goal is to explore the implications of metallicity enrichment for galaxy evolution and the redshift evolution of the UV meta-galactic background. At  $R = 20,000$ , we will perform follow-up high resolution observations to study the absorbing gas kinematics. We aim to construct a  $z \sim 3.5$  MgII TPCF and directly measure the clustering evolution of low ionization gas by comparing it to the  $z \sim 1$  TPCF measured by Churchill et. al [3]. We also plan to compare the MgII TPCF with the CIV TPCF measure by Rauch et. al [6]. The ultimate goal of our research program is (1) to make the unknown UV rest-frame known in the currently unexplored redshift regimes, and (2) to help develop a complete view of the evolution of gas and its role in galaxy and chemical evolution.

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